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# The central plasma sheet temperature, specific entropy, plasma $\beta$-parameter and $K_p$ index during solar maximum

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**Abstract** : The heating process of the plasma in the central plasma sheet (CPS) has been found to be increasing with decreasing plasma pressure and increasing plasma density. The specific entropy of CPS changes in accordance with the temperature $T$ of CPS and plasma $\beta$-parameter The thermal energy in the CPS increases whereas its density decreases with increase of plasma $\beta$-parameter There exist correlations between geomagnetic activity index $K_p$ and sunspot number $\chi$ with temperature and total pressure of the CPS.

**Keywords** : Central plasma sheet temperature, non-adiabatic heating process, substorm events

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## 1. Introduction

The central plasma sheet plays a significant role in global magnetospheric dynamics. Inspite of the extensive studies of the CPS, the heating process of the plasma there has not yet been well understood. In this paper, we try to address this problem.

The CPS is a distinct region in the plasma sheet of geomagnetotail; it contains hot plasma flowing mostly perpendicular to the field intensity $B$ and lowers the wave activity. The plasma in the CPS, exhibits an anti-loss cone distribution which results from the projection into the CPS of the earthward flowing beamlets and from the absence of particles in closed ring type orbits [1]. At the onset of expansive phase of a substorm, heating events in the plasma sheet boundary layer (PSBL) and CPS are found to occur. A major difference between heating mechanisms in the CPS and in the near-earth plasma sheet is that the heating process in non-adiabatic beyond 10 $R_E$ [2]. The second major difference lies in the nature of particle heating. In a limited number of substorm events, the injected particles at geosynchronous orbit undergo betatron acceleration.

During magnetospheric substorms, plasma $\beta$ in the plasma sheet is greater than unity. The wave temperature of the ultra low frequency (ULF) Alfvén wave propagating through the resonance layer of the plasma sheet is found to be a function of plasma $\beta$-parameter and plasma sheet temperature [3]. The geomagnetic activity index, the specific entropy and thermal velocities of electrons and ions depend on the plasma sheet temperature [4]. The validity of the reconnection theory during thinning process of the plasma sheet has also been reported [5].

The purpose of this work is to study the non-adiabatic heating process in the CPS at substorm onsets and the dependence of plasma $\beta$-parameter, geomagnetic activity index $K_p$ and sunspot number on CPS temperature and specific entropy during the selected substorm events.

## 2. ULF wave propagation

Consider the perturbation displacement of a proton in the $z$-direction along a closed field line through CPS with anti-sunward propagating ULF Alfvén waves with wave vector $k = (k_r, k_y, 0)$ and frequency $\omega$. The energy dissipation rate $Q$ is given by [6] as

$$Q = 4\pi^2 \Delta z\, P/\mu_0 \left[\left(T/T_w - 1\right)^2 + \pi^2 k^2 \Delta z^2\right], \tag{1}$$

where
$$T_w = 1/2\, m_i \left(\omega^2/k_\parallel^2\right) \left[\left(k_\perp/k\right) / \left(1 + 2/\beta\right)\right], \tag{2}$$

where $\Delta z$ is the scale length of the gradient of Alfven speed in the resonance layer where the absorption of ULF waves occur; $P$ is the power of the wave with frequency $f$ and amplitude $z$ and is related to the amplitude of magnetic fluctuations; and $m_i$ is the mass of the propagating ion.

## 3. Data and method

The plasma $\beta$-parameter and CPS field intensity $B$ for twenty-two isolated substorm events occurred in the maximum solar activity years 1978–'79, derived from GEOS 2 observations have been collected [7]. The $K_p$ indices and sunspot numbers corresponding to the selected events are collected from Interplanetary medium data book.

The wave temperature $T_w$ of the propagating wave and the energy dissipation rates $Q$ for the 22 events are computed using eqs. (1) and (2). For computing $T_w$ and $Q$, we used $\omega = 20$ kHz, $k_\parallel = k \cdot B/|B|$; $k_\perp = \sqrt{k^2 - k_\parallel^2}$, $\Delta z = 500\,\text{km}$ and $P = 0.005, 0.01, 0.015$ $nT^2$–Hz. We then compute the temperature $T$ from $T_w$ and $Q$, and also specific entropy $\Gamma$ using relation given in [2] and also thermal velocities of electrons $V_e$ and of ions $V_i$ in the CPS during the selected substorm events. The plasma pressure, magnetic pressure and total pressure are also computed for the selected events.

## 4. Results and discussion

The variations of the computed parameters during substorm events have been studied. The variation of $T$ and $P_t$ with plasma $\beta$-parameter is found out. Using statistical correlation methods, the correlation coefficient $R_m$ between geomagnetic activity index $K_p$ and sunspot number $\chi$ is found out and its effect on the temperature $T$ and total pressure $P_t$ of the CPS was verified. The association of CPS temperature with plasma pressure and magnetic pressure has also been verified.

Figure 1 is the graphical representation of the variation of CPS temperature $T$ and specific entropy $\Gamma$ with plasma $\beta$-parameter for different fluctuation levels $P$ of the ULF wave. From Figure 1, it is found that as plasma $\beta$ increases, there is an increase of $T$ and $\Gamma$. Maxima of $T$ and $\Gamma$ obtained corresponding to maximum value of plasma $\beta$. Also when the amplitude of oscillation of ULF wave increases, gradually $T$ and $\Gamma$ increases. From the nature of the curves, we can conclude that the plasma $\beta$-parameter and amplitude of oscillation of the wave through CPS are two important factors which suggests the non-adiabatic heating mechanism in the CPS.

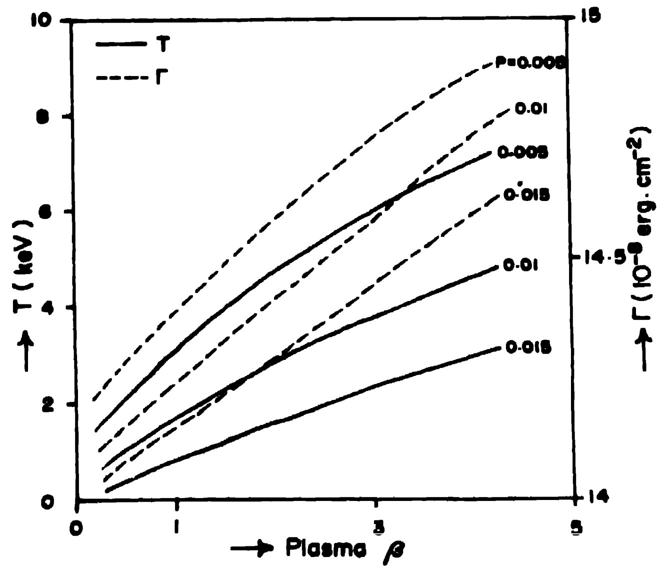


**Figure 1.** Variation of $T$ and $\Gamma$ with plasma $\beta$-parameter.

During the course of a substorm, the plasma $\beta$ and plasma pressure in the plasma sheet increases and hence the energy density increases [2]. In order to maintain pressure balance, total pressure in the plasma sheet must also increase. This is possible only by an adiabatic compression in the plasma sheet or plasma sheet heating. There must be an increase of plasma sheet temperature and specific entropy so that the marginal stability state of the plasma sheet can be attained. This concept is in agreement with the loading-unloading model of substorms [8]. Also from Figure 1, it is clear that if the heating mechanism is adiabatic, $\Gamma$ should be conserved. An increase of $\Gamma$ is due to an increase of thermal energy and simultaneous with a decrease of plasma density.

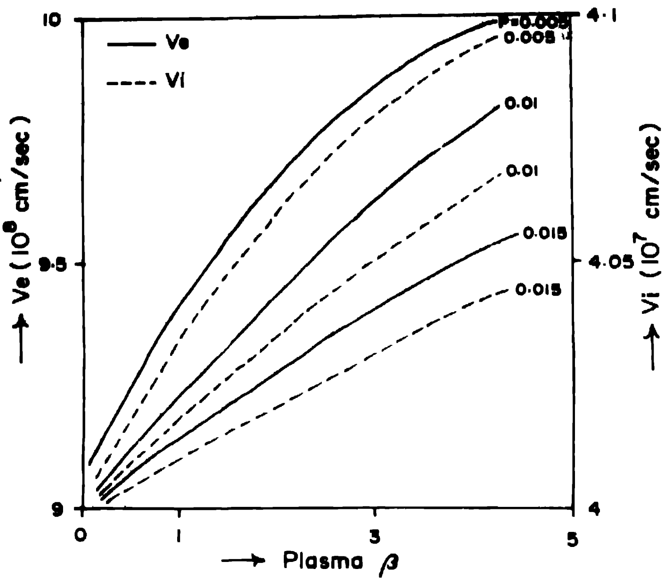


**Figure 2.** $V_e$ and $V_i$ variation with plasma $\beta$-parameter

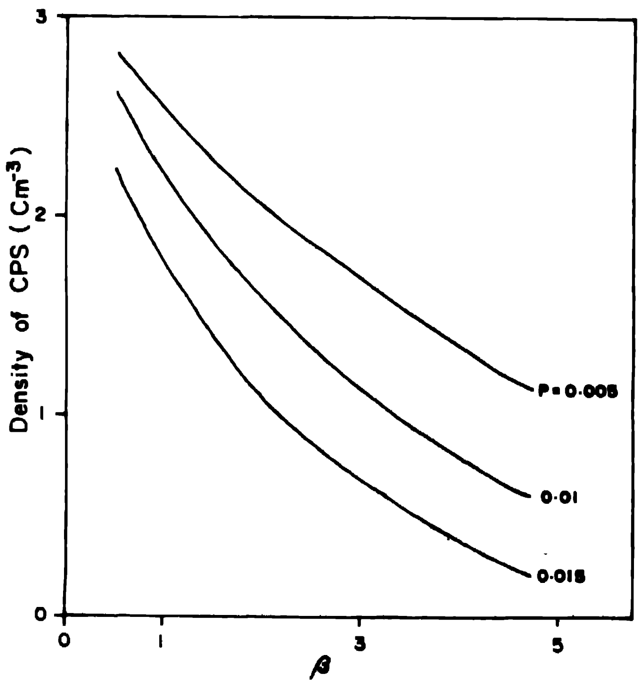


**Figure 3.** CPS density variation with plasma $\beta$-parameter.

Figures 2 and 3 respectively show the variation of the thermal velocities of electrons $V_e$ and of ions $V_i$ and the density of CPS with plasma $\beta$-parameter during the selected substorm events. A continuous increase of $V_e$ and $V_i$ have been obtained with an increase of plasma $\beta$. Maxima and minima of $V_e$ and $V_i$ are obtained corresponding to maximum and minimum values of plasma $\beta$. Also there is an increase of thermal energy in the CPS with plasma $\beta$. From Figure 3, it is found that as plasma -$\beta$ and $P$ increase, there is a continuous decrease of CPS density. To maintain thermal stability in the CPS, the thermal energy and density should be in reverse order. This result is in agreement with the result of [2].

Figure 4 represents the variation of plasma pressure and magnetic pressure in the CPS with the temperature of CPS. There is a sharp increase of plasma pressure corresponding to an increase of CPS temperature. The magnetic pressure fluctuates considerably as CPS temperature increases. Since the magnetic pressure is a function of

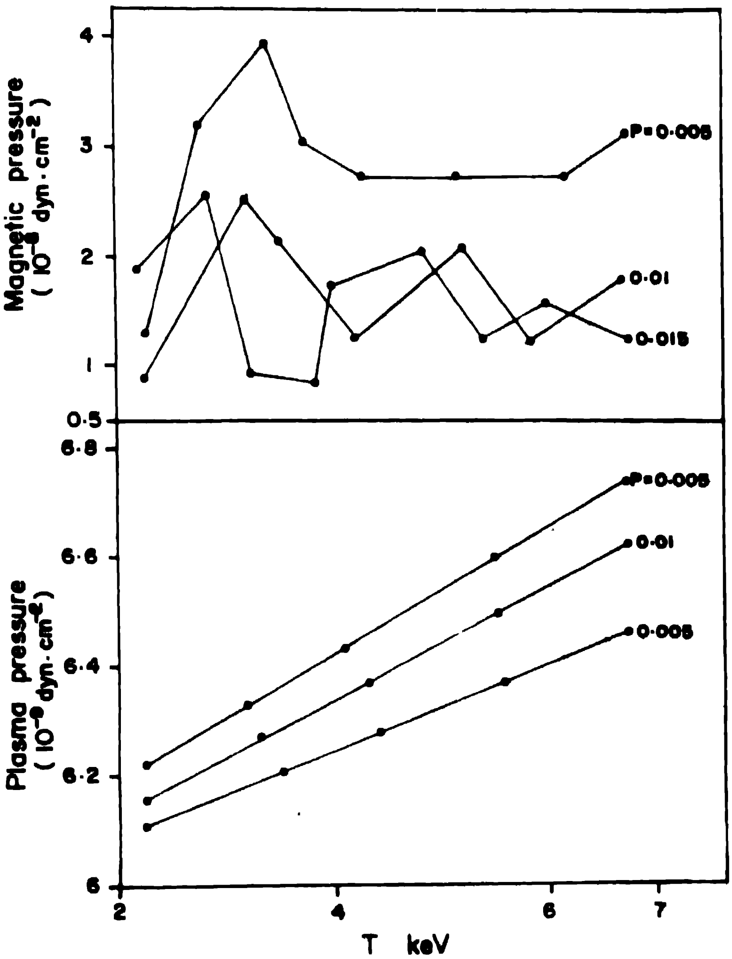


**Figure 4.** Plasma pressure and magnetic pressure variation in the CPS with temperature.

CPS magnetic field $B$, it will obviously change with $B$. The total pressure in the CPS plays a key role in pressure balance and adiabatic processes [9].

Figure 5 shows the variation of the correlation coefficient $R_m$ between geomagnetic activity index $K_p$ and sunspot number $\chi$ with the total pressure $P_t$ and temperature $T$ of the

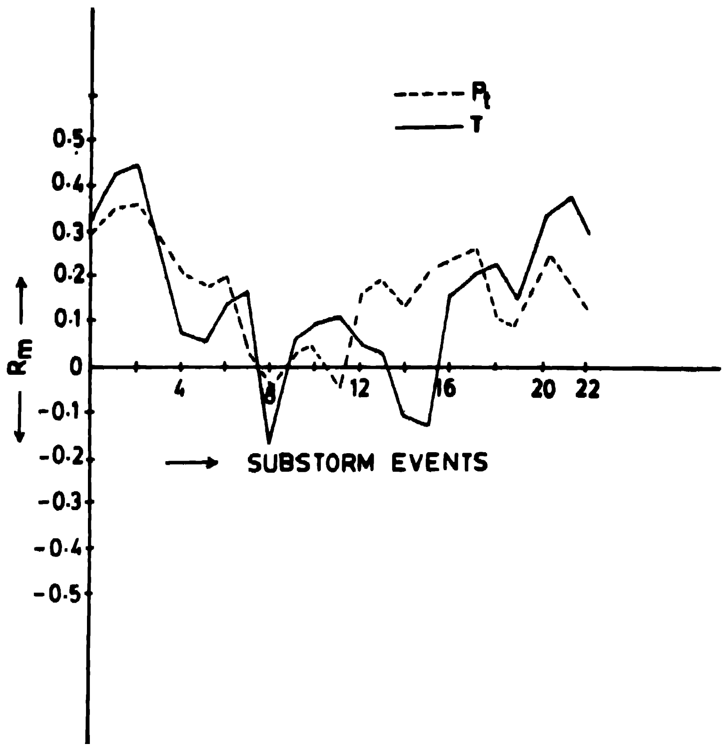


**Figure 5.** The effect of $R_m$ on $T$ and $P_t$.

plasma sheet during some selected substorm events. From Figure 5, we can see that the positive correlations are more frequent than negative correlations. The plasma sheet temperature and AE index correlation during magnetospheric substorms have already been made [10]. However, the present correlation reveals that the temperature is the macroscopic

**Table 1.** Substorm events and their corresponding CPS temperature $T$ and total pressure $P_t$ values.

| Substorm events | UT | $T$ keV | $P_t$ ($10^{-8}$ dyn.cm$^{-2}$) |
|---|---|---|---|
| 1978 | | | |
| 1. Aug. 03 | 2322 | 7.918 | 1.615 |
| 2. Oct. 17 | 1948 | 5.961 | 2.140 |
| 3. Nov. 11 | 2010 | 5.161 | 3.197 |
| 4. Nov. 21 | 2100 | 3.601 | 5.148 |
| 5. Nov. 26 | 1904 | 6.951 | 4.489 |
| 6. Dec. 04 | 1939 | 7.064 | 3.145 |

**Table 1.** *(Cont'd.)*

| | Substorm events | | UT | T keV | $P_t$ ($10^{-8}$ dyn.cm$^{-2}$) |
|---|---|---|---|---|---|
| | 1979 | | | | |
| 7. | Jan. | 22 | 1946 | 6.896 | 2.910 |
| 8. | Jan. | 25 | 2017 | 6.814 | 4.896 |
| 9. | Jan. | 26 | 1918 | 8.663 | 3.464 |
| 10. | Jan. | 27 | 2059 | 6.951 | 5.201 |
| 11. | Feb. | 06 | 2124 | 7.248 | 3.783 |
| 12. | Feb. | 18 | 2028 | 5.489 | 4.141 |
| 13. | Feb. | 26 | 2026 | 5.514 | 3.614 |
| 14. | Mar | 04 | 2237 | 3 918 | 4.561 |
| 15. | Mar. | 24 | 2013 | 6 087 | 2.964 |
| 16 | Mar. | 25 | 1958 | 6 504 | 1.987 |
| 17 | May | 23 | 2035 | 3.241 | 2.910 |
| 18 | May | 27 | 1832 | 3 968 | 5 014 |
| 19 | June | 20 | 2021 | 5 246 | 3.465 |
| 20. | July | 03 | 2151 | 3.217 | 5.482 |
| 21. | July | 16 | 2103 | 4 167 | 2.793 |
| 22. | July | 27 | 0046 | 7.956 | 4.072 |

quantity in the CPS which influences the geomagnetic activity level. The sunspot number also have dependence with $T$ and hence with plasma $\beta$-parameter and total pressure in the CPS. Table 1 gives the computed values of the CPS temperature $T$ and total pressure $P_t$ during the 22 selected substorm events.

## 5. Conclusion

The results of the present study reveal that the temperature in the CPS is a major sink for adiabatic and non-adiabatic processes. During the course of a substorm, the variation of the energization of particles within the CPS was in accordance with plasma $\beta$-parameter and plasma sheet temperature. The knowledge of the specific entropy and total pressure variations will support the heating mechanisms and entropy changes in the substorm triggered CPS. From this work, one can understand the mutual dependence of plasma pressure and density in the CPS during substorms. The current work will also help to account for the chaotic behaviour of CPS during magnetospheric substorms and the dependence of geomagnetic activity in the CPS.

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